



Lessons from the Deep: Exploring the Gulf of Mexico's Deep-Sea Ecosystems Education Materials Collection



Image captions/credits on Page 2.

lesson plan

Keep Away

(adapted from the Expedition to the Deep Slope 2006)

Focus

Effects of pollution on diversity in benthic communities

Grade Level

5-6 (Life Science)

Focus Question

How does pollution affect biological diversity in benthic communities?

Learning Objectives

- Students will be able to discuss the meaning of biological diversity, and will be able to compare and contrast the concepts of variety and relative abundance as they relate to biological diversity.
- Given information on number of individuals, number of species, and biological diversity at a series of sites, students will be able to make inferences about the possible effects of oil drilling operations on benthic communities at these sites.

Materials

- Copies of *Biological Data from Grab Samples Collected in the Vicinity of the Ekofisk Oilfield, North Sea*, one copy for each student group
- Graph paper

Audio/Visual Materials

- Chalkboard, marker board with markers, or overhead transparencies for group discussions

Teaching Time

One 45-minute class period

Seating Arrangement

Groups of 4-6 students

Maximum Number of Students

30

Key Words

Diversity
Diversity index
Species richness
Species evenness
Pollution

Background Information

The Gulf of Mexico produces more petroleum than any other region in the nation, even though its proven reserves are less than those in Alaska and Texas. The *San Francisco Chronicle* reports that oil companies are spending billions to find more crude oil and drill more wells. Even with the threat of more hurricanes, the Gulf of Mexico has advantages: oil workers are not in danger of being kidnapped by armed insurgents as is the case in Nigeria; no foreign president threatens to raise oil companies' taxes, as has happened in Venezuela; and OPEC doesn't control oil production in the Gulf of Mexico. As of August 1, 2005, a total of 41,188 wells had been drilled in the Gulf, and 1,259 petroleum fields had been discovered.

Much of this new exploration is focused on some of the deepest regions of the Gulf, made possible by improved technology and increasing crude oil prices (which have doubled in the last three years). In addition to new petroleum fields, this exploration has led to other discoveries as well. Some of the same conditions responsible for petroleum deposits also provide the basis for biological communities that receive energy from chemicals through a process called chemosynthesis (in contrast to photosynthesis that provides energy to terrestrial and shallow-water communities through processes in which sunlight is the basic energy source).

Deepwater ecosystems in the Gulf of Mexico are often associated with rocky substrates or "hardgrounds." Most of these hard bottom areas are found in locations called cold seeps where hydrocarbons are seeping through the seafloor. Microorganisms are the connection between hardgrounds and cold seeps. When microorganisms consume hydrocarbons under anaerobic conditions, they produce bicarbonate which reacts with calcium and magnesium ions in the water and precipitates as carbonate rock. Two types of ecosystems are typically associated with deepwater hardgrounds in the Gulf of Mexico: chemosynthetic

Images from Page 1 top to bottom:

A close-up mussel aggregation with *Chirodota heheva* sea cucumbers. Image courtesy of Expedition to the Deep Slope 2007.

http://oceanexplorer.noaa.gov/explorations/07mexico/logs/july3/media/cuke_600.html

A CTD rosette being recovered at the end of a cast. Note that the stoppers on the sample bottles are all closed. Image courtesy of INSPIRE: Chile Margin 2010.

<http://oceanexplorer.noaa.gov/explorations/10chile/logs/summary/media/2summary.html>

A methane hydrate mound on the seafloor; bubbles show that methane is continuously leaking out of features like this. If bottom waters warmed, this entire feature may be destabilized and leak methane at a higher rate.

<http://oceanexplorer.noaa.gov/explorations/10chile/background/methane/media/methane4.html>

Lophelia pertusa create habitat for a number of other species at a site in Green Canyon. Image courtesy of Chuck Fisher.

http://oceanexplorer.noaa.gov/explorations/08lophelia/logs/sept24/media/green_canyon_lophelia.html



These small oil droplets have seeped through the sediment and adhered to the top of methane hydrate. Image courtesy of Ian MacDonald, Texas A&M-Corpus Christi.
http://oceanexplorer.noaa.gov/explorations/06mexico/logs/may08/media/oil_on_methane_600.html



These methane mussels (*Bathymodiolus childressi*) live at the edge of Brine Pool NR1 at 650 m depth in the Gulf of Mexico. The pool of brine in the foreground is nearly four times as salty as seawater and is so dense that the submarine can float on the pool to take pictures such as this. Image courtesy Stephane Hourdez.
http://oceanexplorer.noaa.gov/explorations/06mexico/background/plan/media/mussels_600.html



A close-up of the plume of the undescribed *Lamellibrachia* sp., collected during the cruise. The plume consists of the gills and the obturaculum. This specimen will be used to write the formal species description. Image courtesy of Expedition to the Deep Slope.
http://oceanexplorer.noaa.gov/explorations/06mexico/logs/may13/media/plume_486.html

communities and deep-sea coral communities. Hydrocarbon seeps may indicate the presence of undiscovered petroleum deposits, so the presence of these ecosystems may indicate potential sites for exploratory drilling and possible development of offshore oil wells. At the same time, these are unique ecosystems whose importance is presently unknown.

The first chemosynthetic communities were discovered in 1977 near the Galapagos Islands in the vicinity of underwater volcanic hot springs called hydrothermal vents, which usually occur along ridges separating the Earth's tectonic plates (visit <http://www.pmel.noaa.gov/vents/> for more information and activities on hydrothermal vent communities). Chemosynthetic communities in the Gulf of Mexico were found by accident in 1984. These communities are similar in that they are based upon energy produced by chemosynthesis; but while energy for the Galapagos communities is derived from underwater hot springs, deep-sea chemosynthetic communities in the Gulf of Mexico are found in the vicinity of cold seeps. Typical features of communities that have been studied so far include mounds of frozen crystals of methane and water called methane hydrate ice, that are home to polychaete worms and shrimp. Brine pools, containing water four times saltier than normal seawater, have also been found. Researchers often find dead fish floating in the brine pool, apparently killed by the high salinity.

Many species found in deep-water bottom communities are new to science, and may prove to be important sources of unique drugs for the treatment of human diseases. Because their potential importance is not yet known, it is critical to protect these systems from adverse impacts caused by human activities. Ironically, one of the most likely sources of such impacts is the same activity that led to the discovery of these systems in the first place: exploration and development of petroleum resources.

An essential part of strategies to protect deepwater ecosystems is describing deep-water biological communities and evaluating their sensitivity to impacts from human activities. In this activity, students will graph data from an investigation of the effects of oil drilling on marine benthic communities, and use these graphs to make inferences about these effects.

Learning Procedure

1. To prepare for this lesson:
 - a) review the following essays:

Chemosynthetic Communities in the Gulf of Mexico

(<http://oceanexplorer.noaa.gov/explorations/02mexico/background/communities/communities.html>); and

The Ecology of Gulf of Mexico Deep-Sea Hardground Communities

(<http://oceanexplorer.noaa.gov/explorations/06mexico/background/hardgrounds/hardgrounds.html>).

(b) You may also want to review the following visual resources and consider presenting some of these to your students:

Image collections from Sulak, *et al.* (2008). Master Appendix D of this large report contains many images of deep-water coral communities. Download the pdf files “Master Appendix D - Megafaunal Invertebrates of Viosca Knoll, *Lophelia* Community Investigation,” and “Key to Plates in Master Appendix D” from http://fl.biology.usgs.gov/coastaleco/OFR_2008-1148_MMS_2008-015/index.html

Video showing some of the extraordinary biological diversity of the Gulf of Mexico (http://oceanexplorer.noaa.gov/explorations/03mex/logs/summary/media/ngom_biodiversity_cm3.html)

Videos of deepwater corals and coral communities (<http://oceanexplorer.noaa.gov/explorations/09lophelia/logs/photolog/photolog.html>)

Virtual tour of a cold-seep community (http://www.bio.psu.edu/cold_seeps)

Slideshow of highlights from Expedition to the Deep Slope 2006 (<http://oceanexplorer.noaa.gov/explorations/06mexico/background/media/slideshow/slideshow.html>)

Slideshow of images from the Expedition to the Deep Slope 2007 (http://oceanexplorer.noaa.gov/explorations/07mexico/logs/summary/media/slideshow/html_slideshow.html)

2. Lead a discussion of deep-sea chemosynthetic communities. Contrast chemosynthesis with photosynthesis. In both processes, organisms build sugars from carbon dioxide and water. This process requires energy; photosynthesizers obtain this energy from the sun, while chemosynthesizers obtain energy from chemical reactions. Point out that there are a variety of chemical reactions that can provide this kind of energy. Contrast hydrothermal vent communities with cold-seep communities.

Discuss the importance of the Gulf of Mexico to U.S. petroleum resources, as well as the potential importance of deep-sea biological communities that might be adversely affected by exploration and development of petroleum resources. Ask students to brainstorm steps that might be taken to avoid adverse impacts. Tell students that one of the ways scientists describe and compare biological communities is based on the concept of biological diversity, also called biodiversity.

3. Review the concept of biological diversity. Scientists often use the term “species diversity” to describe the abundance of species and individuals within an area (or environment). The simplest measure of species diversity is the number of species present in an area. This is called species richness. But there is more to diversity than just the number of species present. A community that has more or less equal numbers of individuals within the species present is usually thought of as more diverse than a community that is dominated by one species.

Species diversity tends to increase at the edges of environments (ecotones) where conditions are more variable. Species diversity is often used as a measure of environmental health; diversity is generally expected to decline in a stressed environment. For more background and activities on species diversity, visit the Arbor Project’s Web page on bird biodiversity at www.cees.iupui.edu/Education/Workshops/Project_Seam/Exercises/bird_biodiversity_exercise.htm.

4. Tell students that they are going to analyze data from an investigation of the effects of oil drilling on marine benthic communities. Their assignment is to use their analyses to make inferences about these effects.

Provide each student group with a copy of *Biological Data from Grab Samples Collected in the Vicinity of the Ekofisk Oilfield, North Sea* (grab samples are samples collected from the sea bottom with a device that resembles a giant clam shell). Have students sort the data into four groups: samples collected less than 500 m from the drilling platform, samples collected between 500 and 1,000 m, samples collected between 1,000 and 3,000 m, and samples collected more than 3,000 m from the platform. For each of these four groups, student should find the mean number of individuals, mean number of species, and mean diversity. Students should then construct three bar graphs, one each for mean number of individuals, mean number of species, and mean diversity, with the distance interval on the horizontal axis.

5. Lead a discussion of students' results. Means for each interval should be:

Distance from Drilling Platform (meters)	Mean Number of Individuals	Mean Number of Species	Mean Diversity
0-500	412	57	1.73
500-1,000	294	104	2.20
1,000-3,000	254	148	2.05
>3,000	152	113	2.05

Ask students which of the four groups they would expect to be most affected by drilling operations, and how this group differs from the other groups. Students should identify the group of samples collected less than 500 m from the platform as the most likely to be affected, and should notice that this group has more individuals, fewer species, and lower diversity than the other groups. A probable explanation for these observations is that fewer species were able to tolerate effects produced by drilling operations, so the number of species and diversity were decreased; but individuals belonging to species that could tolerate these conditions faced less competition from other species, and so there were more individuals of the tolerant species.

Ask students to infer what is happening at sites 500 – 1,000 m from the drilling platform. Here the number of species is less than at sites farther away from the platform, but more than at sites closer to the platform. This suggests that conditions at the 500 – 1,000 m sites were unfavorable to some species found at more distant sites, but still tolerable to others that are missing from sites closer to the platform. The number of individuals at the 500 – 1,000 m sites was higher than any of the other sites, perhaps because of reduced competition. Since the number of species was still fairly high, this increase in individuals caused the diversity to be higher (remember that diversity considers numbers of individuals as well as number of species).

Ask students to interpret results from the groups that were 1,000 – 3,000 m and >3,000 m from the drilling platform. The diversity of these two groups is identical, yet the more distant group has fewer species and fewer individuals. One possible explanation is that low levels of pollution at the 1,000 – 3,000 m sites caused some species to disappear, but this allowed other species to come into the area. Another possibility is that these sites in these two groups were influenced by one or more factors other than the drilling platform.

The Bridge Connection

www.vims.edu/bridge/ – Click on “Ocean Science” in the navigation menu to the left, then “Habitats,” then “Deep Sea” for resources on deep-sea communities.

The “Me” Connection

Have students write a short essay describing how biological diversity is important to their own lives.

Connections to Other Subjects

English/Language Arts, Mathematics

Assessment

Graphs prepared in Step 4 provide an opportunity for assessment. In addition, you may want to have each group prepare a written interpretation of their results prior to the group discussion in Step 5.

Extensions

See the “Resources” section of *Lessons from the Deep: Exploring the Gulf of Mexico's Deep-sea Ecosystem Education Materials Collection Educators Guide* for additional information, activities, and media resources about deepwater ecosystems in the Gulf of Mexico.

Multimedia Discovery Missions

<http://www.learningdemo.com/noaa/> Click on the links to Lessons 3, 5, and 6 for interactive multimedia presentations and Learning Activities on Deep-Sea Corals, Chemosynthesis and Hydrothermal Vent Life, and Deep-Sea Benthos.

Other Relevant Lesson Plans from NOAA's Ocean Exploration Program

Let's Make a Tubeworm! (15 pages, 1946 KB)

<http://oceanexplorer.noaa.gov/oceanos/explorations/10index/background/edu/media/tubeworm.pdf>

Focus - Symbiotic relationships in cold seep communities (Life Science)

Students describe the process of chemosynthesis in general terms, contrast chemosynthesis and photosynthesis, describe major features of cold-seep communities, and list at least five organisms typical of these communities. They will be able to define symbiosis, describe two examples of symbiosis in cold-seep communities, describe the anatomy of vestimentiferans, and explain how these organisms obtain their food.

Animals of the Fire Ice (5 pages, 364 KB)

<http://oceanexplorer.noaa.gov/oceanos/edu/lessonplans/media/09animalsoffireice.pdf>

Focus - Methane hydrate ice worms and hydrate shrimp (Life Science)

Students define and describe methane hydrate ice worms and hydrate shrimp, infer how methane hydrate ice worms and hydrate shrimp obtain their food, and infer how methane hydrate ice worms and hydrate shrimp may interact with other species in the biological communities of which they are part.

Microfriends (6 pages, 420 KB)

<http://oceanexplorer.noaa.gov/oceanos/edu/lessonplans/media/09microfriends.pdf>

Focus - Beneficial microorganisms (Life Science)

Students describe at least three ways in which microorganisms benefit people, describe aseptic procedures, and obtain and culture a bacterial sample on a nutrient medium.

Other Links and Resources

The Web links below are provided for informational purposes only. Links outside of Ocean Explorer have been checked at the time of this page's publication, but the linking sites may become outdated or non-operational over time.

<http://oceanexplorer.noaa.gov/> – Ocean Explorer Web site

Gray, J. S., K. R. Clarke, R. M. Warwick, and G. Hobbs. 1990. Detection of initial effects of pollution on marine benthos: an example from the Ekofisk and Eldfisk oilfields, North Sea. *Marine Ecology Progress Series* 66:285-299 – Technical journal article upon which this activity is based.

<http://www.piersystem.com/go/site/2931/> – Main Unified Command Deepwater Horizon response site

<http://response.restoration.noaa.gov/deepwaterhorizon> – NOAA Web site on Deepwater Horizon Oil Spill Response

http://docs.lib.noaa.gov/noaa_documents/NESDIS/NODC/LISD/Central_Library/current_references/current_references_2010_2.pdf – Resources on Oil Spills, Response, and Restoration: a Selected Bibliography; document from NOAA Central Library to aid those seeking information concerning the Deepwater Horizon oil spill disaster in the Gulf of Mexico and information on previous spills and associated remedial actions; includes media products (web, video, printed and online documents) selected from resources available via the online NOAA Library and Information Network Catalog (NOAALINC)

<http://www.gulfallianceeducation.org/> – Extensive list of publications and other resources from the Gulf of Mexico Alliance; click “Gulf States Information & Contacts for BP Oil Spill” to download the Word document

<http://rucool.marine.rutgers.edu/deepwater/> – Deepwater Horizon Oil Spill Portal from the Integrated Ocean Observing System at Rutgers University

http://www.darrp.noaa.gov/southeast/deepwater_horizon/index.html – Information about damage assessments being conducted by NOAA's Damage Assessment Remediation and Restoration Program

<http://response.restoration.noaa.gov/> – Click “Students and Teachers” in the column on the left for information, fact sheets, and activities about oil emergencies, habitats, and other ocean issues

<http://www.noaa.gov/sciencemissions/bpoilspill.html> – Web page with links to NOAA Science Missions & Data relevant to the Deepwater Horizon/BP Oil Spill

<http://ecowatch.ncddc.noaa.gov/jag/data.html> – Data Links page on the Deepwater Horizon Oil Spill Joint Analysis Group Web site

<http://ecowatch.ncddc.noaa.gov/jag/reports.html> – Reports page on the Deepwater Horizon Oil Spill Joint Analysis Group Web site

http://www.education.noaa.gov/Ocean_and_Coasts/Oil_Spill.html – “Gulf Oil Spill” Web page from NOAA Office of Education with links to multimedia resources, lessons & activities, data, and background information

<http://www.geoplatform.gov/gulfresponse/> – Web page for GeoPlatform.gov/gulfresponse—an online map-based tool developed by NOAA with the EPA, U.S. Coast Guard, and the Department of Interior to provide a “one-stop shop” for spill response information; includes oil spill trajectory, fishery area closures, wildlife data, locations of oiled shoreline and positions of deployed research ships

Fisher, C., H. Roberts, E. Cordes, and B. Bernard. 2007. Cold seeps and associated communities of the Gulf of Mexico. *Oceanography* 20:118-129; available online at http://www.tos.org/oceanography/issues/issue_archive/20_4.html

Sulak, K. J., M. T. Randall, K. E. Luke, A. D. Norem, and J. M. Miller (Eds.). 2008. *Characterization of Northern Gulf of Mexico*

Deepwater Hard Bottom Communities with Emphasis on *Lophelia* Coral - *Lophelia* Reef Megafaunal Community Structure, Biotopes, Genetics, Microbial Ecology, and Geology. USGS Open-File Report 2008-1148; http://fl.biology.usgs.gov/coastaleco/OFR_2008-1148_MMS_2008-015/index.html

National Science Education Standards

Content Standard A: Science As Inquiry

- Abilities necessary to do scientific inquiry
- Understanding about scientific inquiry

Content Standard C: Life Science

- Populations and ecosystems

Content Standard F: Science in Personal and Social Perspectives

- Populations, resources, and environments

Ocean Literacy Essential Principles and Fundamental Concepts

Essential Principle 1.

The Earth has one big ocean with many features.

Fundamental Concept h. Although the ocean is large, it is finite and resources are limited.

Essential Principle 4.

The ocean makes Earth habitable.

Fundamental Concept b. The first life is thought to have started in the ocean. The earliest evidence of life is found in the ocean.

Essential Principle 5.

The ocean supports a great diversity of life and ecosystems.

• *Fundamental Concept b.* Most life in the ocean exists as microbes. Microbes are the most important primary producers in the ocean. Not only are they the most abundant life form in the ocean, they have extremely fast growth rates and life cycles.

Fundamental Concept c. Some major groups are found exclusively in the ocean. The diversity of major groups of organisms is much greater in the ocean than on land.

Fundamental Concept d. Ocean biology provides many unique examples of life cycles, adaptations and important relationships among organisms (such as symbiosis, predator-prey dynamics and energy transfer) that do not occur on land.

• *Fundamental Concept f.* Ocean habitats are defined by environmental factors. Due to interactions of abiotic factors such as salinity, temperature, oxygen, pH, light, nutrients, pressure, substrate and circulation, ocean life is not evenly distributed temporally or spatially, i.e., it is "patchy". Some regions of the ocean

support more diverse and abundant life than anywhere on Earth, while much of the ocean is considered a desert.

Fundamental Concept g. There are deep ocean ecosystems that are independent of energy from sunlight and photosynthetic organisms. Hydrothermal vents, submarine hot springs, and methane cold seeps rely only on chemical energy and chemosynthetic organisms to support life.

Essential Principle 6.

The ocean and humans are inextricably interconnected.

Fundamental Concept b. From the ocean we get foods, medicines, and mineral and energy resources. In addition, it provides jobs, supports our nation's economy, serves as a highway for transportation of goods and people, and plays a role in national security.

• *Fundamental Concept e.* Humans affect the ocean in a variety of ways. Laws, regulations and resource management affect what is taken out and put into the ocean. Human development and activity leads to pollution (such as point source, non-point source, and noise pollution) and physical modifications (such as changes to beaches, shores and rivers). In addition, humans have removed most of the large vertebrates from the ocean.

Fundamental Concept g. Everyone is responsible for caring for the ocean. The ocean sustains life on Earth and humans must live in ways that sustain the ocean. Individual and collective actions are needed to effectively manage ocean resources for all.

Essential Principle 7.

The ocean is largely unexplored.

Fundamental Concept a. The ocean is the last and largest unexplored place on Earth—less than 5% of it has been explored. This is the great frontier for the next generation's explorers and researchers, where they will find great opportunities for inquiry and investigation.

Fundamental Concept b. Understanding the ocean is more than a matter of curiosity. Exploration, inquiry and study are required to better understand ocean systems and processes.

Fundamental Concept d. New technologies, sensors and tools are expanding our ability to explore the ocean. Ocean scientists are relying more and more on satellites, drifters, buoys, subsea observatories and unmanned submersibles.

Fundamental Concept f. Ocean exploration is truly interdisciplinary. It requires close collaboration among biologists, chemists, climatologists, computer programmers, engineers, geologists, meteorologists, and physicists, and new ways of thinking.

We value your feedback on this lesson.

Please e-mail your comments to: oceanexeducation@noaa.gov

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Student Handout:

Biological Data from Grab Samples Collected in the Vicinity of the Ekofisk Oilfield, North Sea

(from Gray, *et al.*, 1990)

Distance from Drilling Platform (meters)	Number of Individuals	Total Number of Species	Diversity
120	362	47	1.60
235	462	67	1.86
340	392	42	1.63
450	432	72	1.83
600	274	84	2.00
720	314	124	2.40
850	289	99	2.10
950	299	109	2.30
1150	260	140	2.01
1250	248	156	2.09
2375	244	138	2.04
2800	264	158	2.06
3100	140	105	2.03
3800	164	121	2.07
4200	148	118	2.10
4900	156	108	2.00